FIRST RESULTS OF DUST INJECTION IN T-10 PLASMA

V.Yu. Sergeev[1], V.G. Skokov[1], V.M. Timokhin[1], B.V. Kuteev[2], S.V. Krylov[2], Yu.V. Martynenko[2], L.N. Khimchenko[2]

[1]State Polytechnical University, St. Petersburg, Russia, e-mail: skokov@phtf.stu.neva.ru;
[2]Nuclear Fusion Institute, Russian Research Center "Kurchatov Institute", Moscow, Russia, e-mail: kuteev@nfi.kiae.ru

First results of T-10 injection experiments of the carbon dust particles with 2-10 μm diameter and 40-300 m/s velocity are presented. Different scenarios of the dust injection were tested. The dust particles ablation was studied. An approach for determination of a dust particle penetration length was developed. Measured penetration depths (3-7 cm) are compared with the simulation by the ablation model. The μm range of the separate dust particle diameters derived from the ablation data was close to sizes of the dust injected assuming that an acceleration of the separate particle is similar to the large carbon pellet in the pellet injector.

PACS: 52.55.-s, 52.40.-w

INTRODUCTION

Dust generation and transport in high temperature plasmas create substantial problems on the way to fusion reactor with magnetic confinement [1]. The dust affects likely operation regimes of the divertor and core plasma in tokamaks and stellarators. Study of dust interaction with tokamak plasma is an important task of the fusion reactor physics and technology.

EXPERIMENTAL SETUP

The carbon dust injection experiments were carried out in T-10 tokamak during summer 2005. 9 shots with different types of dust penetration into plasma were registered.

The injected material was carbon dust with the size in a range of 2-10 μm. The impurity gas-dynamic pellet injector [2] with multi-charge magazine was used for the dust injection. The helium jet of 25 bar pressure accelerated the injected materials to in 50-300 m/s. The dust ablation was observed by the diagnostic system from directions, which were perpendicular to the injection trajectory from outward torus direction. The diagnostic system contains the wide view angle photodetector (PD), the matrix of 8 narrow collimated photodetectors (ND) and the video registration system (CCD) (see Fig. 1) supplied by the carbon ion CII line (723 nm) interference filters. The exposure time of the CCD camera was 20 ms, which was much larger than the dust ablation time in the plasma.

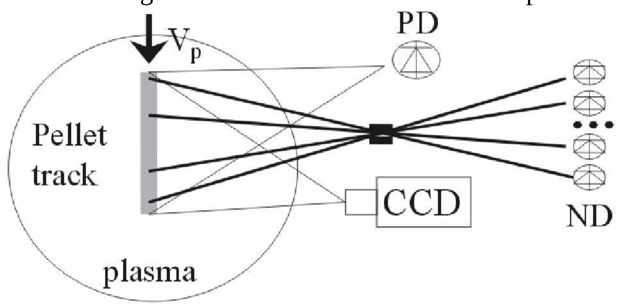

Fig. 1. Layout of the impurity pellet experiment in T-10

The main tasks of these first experiments were as follows: development of the dust loading procedure into injector and optimization of the dust acceleration process, study applicability of pellet diagnostics for the dust observation.

The dust loading into the injector magazine met the certain difficulties. The loading of the pre-determined and measured quantity of the dust was impossible due to the dust exhausting through small gaps between movable and immovable components of the injector magazine. Thus, only a few uncontrolled dust particles could be injected into the plasma from shot to shot. In a case of the stopped magazine we can provide the dust load only for one plasma shot without disassembling the whole system. In this case, the dust could be accelerated with a rather wide velocity distribution. It results in increase of the time duration of the dust input process that makes the operation difficulties of the injection, i.e. puff of the propellant gas during a long time may influence on the plasma conditions.

EXPERIMENTAL RESULTS AND DISCUSSION

Massive dust injection

The most representative result was obtained in T-10 shot #41132 with following parameters: I_{pl} = 295 kA, $n_e = 3.9\times10^{13}$ cm^{-3}, T_e = 1275 keV, B = 2.41 T, a_L = 30 cm, Ohmic heating discharge.

The PD signal had low noise-to-signal ratio due to low light emission intensity so both subtraction of the electric breakthrough and smoothing (with constant of 170 μs for mitigation of the electric noise) were done. A time evolution of the processed PD signals is shown in Fig. 2.

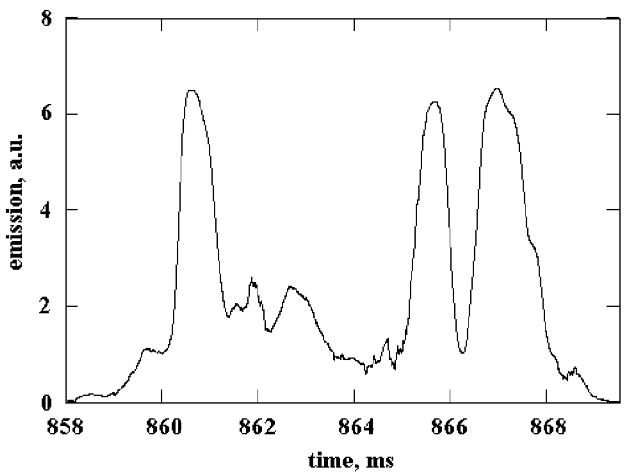

Fig. 2. Light emission of big dust amount ablating

The propagating gas valve of the pellet injector was opened at 795.3 ms. At this moment the dust flow acceleration began. One can assume that the dust particles leave pellet magazine, enter the barrel and accelerate in the helium jet during the whole the time when the gas valve is opened. It can be confirmed by the signal of the first light barrier, which is placed on the end of the barrel on 11 cm distance from the initial dust position. It starts to register the dust flight at $t_{barr} \cong 795.9$ ms and ends at 800.5 ms, which correlates with the gas valve closing. Thus, duration of the dust flow at the injector exit was $\Delta t_{dist\_barr} \approx 4.5$ ms.

The distance from the first light barrier to the plasma periphery is $L \cong 250$ cm. We assume that the CII light emission from plasma is proportional to the ablation rate of dust injected [3]. One can see that time duration of the dust flow input to the plasma is about $\Delta t_{dist\_pl} \approx 10$ ms and Δt_{dist_pl} is two times larger then Δt_{dist_barr}. Besides, there are three maximums at 860.5 ms, $t_{pl} \cong 865.5$ ms and 867 ms. Reasons for the presence of these maximums is not clear yet. There are difficulties with extraction of the emission of the separate dust particles from the PD signal. The data obtained allow us to estimate an averaged dust velocity $L/(t_{pl} - t_{barr}) \cong 37$ m/s in a case of the massive dust injection.

In Fig. 3 the CCD photo of ablating dust cloud is presented. The *X*- axis shows a distance in cm from the pellet injector axis (shown by arrow in the figure) in the toroidal direction. The *Y*-axis shows the distance in cm from the T-10 tokamak midplane. One can see that the effective dust penetration length in the vertical direction is ≈ 10 cm but it might be larger then a real penetration length of separate dust particles due to their scattering relative to the injector axis (see below).

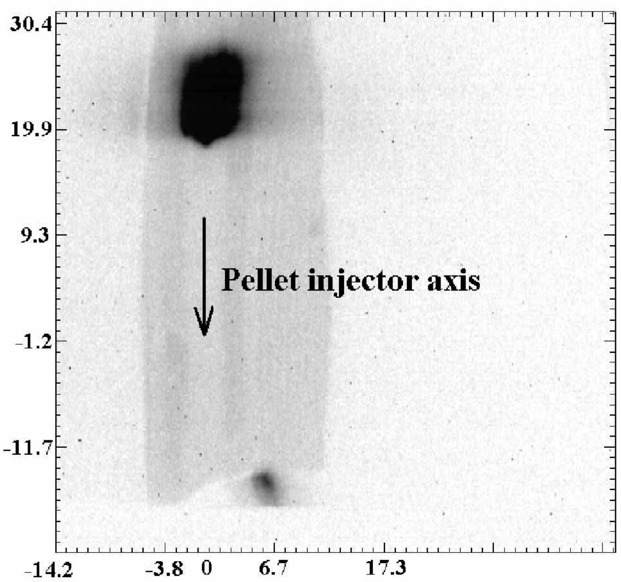

Fig. 3. CCD photo of dust cloud ablating

Several dust particles injection

In this injection approach the more informative experimental data sets were obtained in T-10 #41153, #41107, #41150 shots. The plasma parameters were as follows: I_{pl} = 280-300 kA, $n_e = 4.0\text{-}4.8\times10^{13}$ cm^{-3}, Ohmic discharge. In these shots the 3-5 ablation tracks of dust particles were clearly observed on the CCD pictures. Unfortunately, it was difficult to extract the dust emission from the PD signal due to their low emission intensities in comparison with the background emission intensity of the ambient plasma.

The dust tracks measured by the CCD camera for shot #41153 is shown in Fig. 4. The axes are the same as in Fig. 3. One can see from Fig. 4 surprisingly deep "effective" penetration of the dust particles under assumption that all dust particles entered to the plasma along the pellet injector axis. This problem can be resolved taking into account a cone angle distribution of the dust particles leaving the pellet injector barrel.

Estimations made below were done under the following assumptions: 1) the dust particles have a dispersion in the plane perpendicular to the plane of the photo in Fig. 4; 2) the dust particle No. 1 in Fig. 3 has no dispersion; 3) ablation of every dust particle started at the same 27.5 cm plasma minor radius. In this case we can find geometry of the dust particle tracks shown schematically in Fig. 5. In the figure, cross is a plasma center, circle is the minor radius of the dust ablation start.

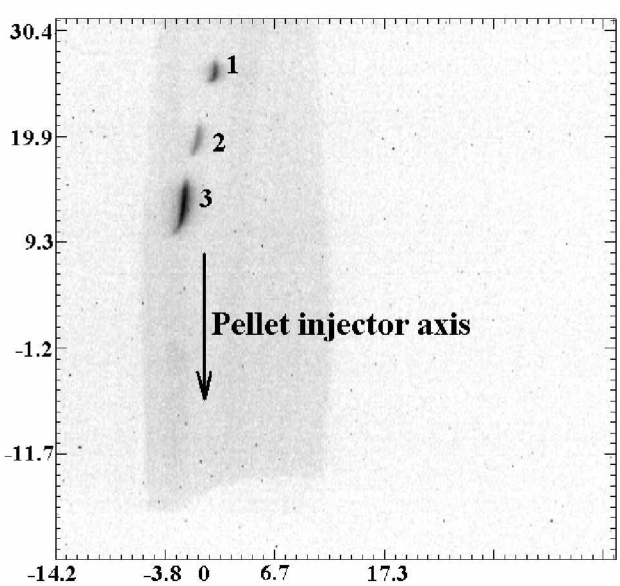

Fig. 4. Pellet clouds complete integral photograph

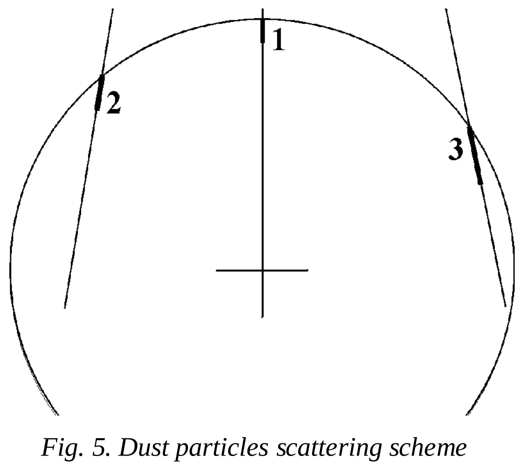

Fig. 5. Dust particles scattering scheme

Thus, one can evaluate the scattering angles, target parameter (distance from the plasma center to the dust track), penetration depth minor radius, and track lengths. These results are presented in Table 1.

Table 1. Geometry parameters of dust particles tracks

Particle number	Scattering angle, degrees	Target parameter, cm	Penetration depth, cm	Track length, cm
1	0	0	24.9	2.8
2	9.2	20.6	25.1	4.0
3	11.3	25.2	25.6	6.6

The same evaluations carried out for shots #41107 and #41150 demonstrate similar results presented above.

From Fig. 4 one can see toroidal accelerations of the dust particles. This effect is similar to that observed for the large pellets in tokamaks [4] and, therefore, can be connected with asymmetry of the heat flux on the pellet surface due to the toroidal electric filed providing the plasma current.

Dust particles ablation simulation

Unfortunately, the dust particles velocities couldn't be measured due to the problem with PD signal measurements discussed above. Ablation simulations were done for two margin values of the dust particle pellet velocity: 1) V_p = 300 m/s is being equal to the averaged carbon large pellet velocity for the pellet injector settings used in experiments; 2) V_p = 40 m/s is estimated for shot #41132 in the case of massive dust injection. The simulation used the Neutral Gas Shielding Model [5]. During the simulation the particle diameter was selected to fit its simulated track length to the track length measured from the CCD camera image. Simulation results for shot #41153 are presented in Table 2.

Table 2. Simulated diameters of dust particles in #41153

Particle number	Particle diameter, µm (V_p = 300 m/s)	Particle diameter, µm (V_p = 40 m/s)
1	6.2	41
2	7.8	51
3	9.8	65

Through the whole statistics (10 clearly visible tracks of dust particles in 3 shots) we obtain the following ranges of the dust particle diameters: 1-13 µm for V=300 m/s and 5-85 µm for V=40 m/s. Comparing these values with the predetermined dust particles size range one can make a conclusion that in the case of small amount of dust particles being injected into plasma they are accelerated up to the large pellet velocity.

CONCLUSIONS

Experiments on carbon dust being injected by impurity pellet injector by different approaches into T-10 tokamak plasma were carried out. Dust particles ablation was measured by different techniques. An approach for determination of a dust particle penetration length was developed. Measured penetration depths (3-7 cm) are compared with the simulation by the ablation model. The estimated ablated particle diameters in µm range are close to real dust sizes assuming that an acceleration of the separate particle is similar to the large carbon pellet in the pellet injector.

REFERENCES

1. G. Federici, C.H. Skinner, J.N. Brooks et al. // *Nuclear Fusion*. 2001, v. 41, p.1967.
2. V.A. Belopolsky, V.G. Skokov, V.M. Timokhin et al. Studies of Carbon Pellet Ablation in T-10 Plasmas // *30th EPS conference on Plasma Phys. and Contr. Fusion*, St. Petersburg, 7-11 July 2003 / ECA, 2003, v. 27A, P-3.117.
3. L. Ledl, R. Burhenn, L. Lengyel et al. Study of carbon pellet ablation in ECR-heated W7-AS plasmas // *Nuclear Fusion*. 2004, v. 44, p. 600.
4. S.M. Egorov et al. Current density profile and electron beam localization measurements using carbon pellets on T-10 // *Nuclear Fusion*. 1992, v. 32, N 11, p. 2025.
5. B.V. Kuteev, V.Yu. Sergeev, L.D. Tsendin // *Soviet Journal of Plasma Physics*. 1984, v. 10, p. 675.

ПЕРВЫЕ РЕЗУЛЬТАТЫ ПО ИНЖЕКЦИИ ПЫЛИ В ПЛАЗМУ Т-10

В.Ю. Сергеев, В.Г. Скоков, В.М. Тимохин, Б.В. Кутеев, С.В. Крылов, Ю.В. Мартыненко, Л.Н. Химченко

Представлены первые результаты экспериментов по инжекции углеродных пылевых частиц диаметром 2-10 мкм со скоростями 40-300 м/с в Т-10. Протестированы различные сценарии инжекции пыли. Исследовано испарение пылевых частиц. Разработана приблизительная методика определения глубины проникновения пылевых частиц. Измеренные глубины проникновения (3-7 см) сравнивались с расчетами по модели испарения. Оцененные микронные диаметры частиц, полученные из данных по испарению, близки к размерам инжектированной пыли, в предположении того, что отдельные частицы ускоряются так же, как и при инжекции крупных пеллетов.

ПЕРШІ РЕЗУЛЬТАТИ ПО ІНЖЕКЦІЇ ПИЛУ В ПЛАЗМУ Т-10

В.Ю. Сергєєв, В.Г. Скоков, В.М. Тимохін, Б.В. Кутєєв, С.В. Крилов, Ю.В. Мартиненко, Л.Н. Хімченко

Представлено перші результати експериментів по інжекції вуглецевих пилових часток діаметром 2-10 мкм зі швидкостями 40-300 м/с у Т-10. Протестовано різні сценарії інжекції пилу. Досліджено випар пилових часток. Розроблено приблизну методику визначення глибини проникнення пилових часток. Обміряні глибини проникнення (3-7 см) порівнювалися з розрахунками по моделі випару. Оцінені мікронні діаметри часток, отримані з даних по випару, є близькими до розмірів інжектованого пилу, у припущенні того, що окремі частки прискорюються так само, як і при інжекції великих пелетів.